On the BELLE Charmonium States

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Abstract

It is shown that newly performed experimental studies by the Belle Collaboration are excellently incorporated in the unified picture for hadron spectra developed early. From our analysis it follows that the measured values for the masses of the BELLE states exactly coincide with the calculated masses of the states living in the corresponding KK towers.

Quite recently the Belle Collaboration [1] reported the observation of an enhancement in the $\omega J/\psi$ invariant mass distribution for exclusive $B \to K\omega J/\psi$ decays. The statistical significance of the $\omega J/\psi$ mass enhancement was estimated to be greater than 8σ. The results were obtained from a 253 fb^{-1} data sample that contains 274 million $B\bar{B}$ pairs that were collected near the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric energy e^+e^- collider.

The reported fits to the individual 40 MeV-wide bins of $M(\omega J/\psi)$ are plotted in Figs. 1(a) and (b) extracted from original paper [1]. An enhancement is evident around $M(\omega J/\psi) = 3940$ MeV. The curve in Fig. 1(a) is the result of a fit with the same threshold function which has been used to fit the phase-space MC distribution. The fit quality in that case is poor ($\chi^2/dof = 133/11$), indicating a significant deviation from phase-space.

Figure 1(b) shows the results of a fit where an S-wave Breit Wigner function has been included to represent the enhancement; see, however, the details in [1]. The fit with $\chi^2/dof = 18.8/8$ (CL = 1.6%) yielded a Breit-Wigner signal with a mass $M = 3941 \pm 11$ MeV and a width $\Gamma = 92 \pm 24$ MeV (statistical errors only). It was pointed out that the Breit Wigner fit parameters are sensitive to the shape used to model the background. For example, if the background function is replaced with a second-order polynomial function, then the mass is changed to 3949 ± 9 MeV, the width is changed to $\Gamma = 112 \pm 25$ MeV and the fit quality is improved: $\chi^2/d.o.f. = 11.8/6$ (CL=6.7%). For the average from the two fits one obtains a mass $M = 3945 \pm 10$ MeV and a width $\Gamma = 102 \pm 24.5$ MeV.

Earlier, in September of 2003 at the 10th International Conference on Hadron Spectroscopy (Ashaffenburg, Germany, 31 August – 6 September 2003), the Belle Collaboration reported [2, 3, 4] the discovery of very narrow $X(3872)$-meson state with a mass of

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3872.0±0.6(stat)±0.5(syst) MeV ($\Gamma^{tot}_{X(3872)} < 2.3 MeV$ 95% C.L.) in the $\pi^+\pi^- J/\psi$ invariant mass distribution in the B decay $B^{\pm} \to K^{\pm}\pi^+\pi^- J/\psi$, where it was also established that the $\pi^+\pi^-$ invariant mass for the $X(3872)$ signal region concentrated at the ρ mass. This observation of the Belle Collaboration was soon confirmed by CDF at Fermilab [5]. The mass measurement presented by CDF 3871.4 ± 0.7 ± 0.4 MeV is in agreement with the result of Belle. It should be noted, in particular, that the mass 3872 MeV is very near the $D^0\bar{D}^{*0}$ threshold, while the D^+D^{*-} channel with approximately 8 MeV higher threshold mass is forbidden for $X(3872)$ decay by phase space. What is non-trivial here that the $X(3872)$ state has been observed at the mass which is surprisingly far from the predictions of conventional quark potential models. It is still more remarkable that the observed state $X(3872)$ was very narrow. The small width was found to be in contradiction with quark model expectations too.

Many attempts have been made to understand the $X(3872)$ state as a simple $c\bar{c}$ charmonium state. A comparative analysis of many possible $c\bar{c}$ assignments for the $X(3872)$ state has been presented in comprehensive paper [6] where some non-$c\bar{c}$ $X(3872)$ assignments have been considered as well. However, the mechanism which keeps this state narrow is unclear so far. It is even quite unclear how the $X(3872)$ meson could be understood as the state of a simple $c\bar{c}$ quark system, this is extremely problematic in the framework of phenomenology based on conventional quark models. The most quark potential models predict 1D states about 50–100 MeV below the $X(3872)$ mass, and the 2P states are predicted to lie above the $X(3872)$ by a similar amount [6]. That is to say, the $X(3872)$ mass is a subject that is to be explained in the conventional quark potential models.

In our talk [7] presented at the same 10th International Conference on Hadron Spectroscopy, where some of our previous studies were partially summarized, we have reported a new theoretical concept to create quite a new scheme of systematics for hadron states providing a unified picture for hadron spectra. The fundamental Kaluza-Klein hypothesis on existence of the extra dimensions with a compact internal extra space together with some novel dynamical ideas have been taken as a base of our approach to hadron spectroscopy. In our theoretically developed concept the observed hadron states occupy the storeys and live in the corresponding KK towers built in according to the established general physical law. We have pointed out that the BELLE $X(3872)$ state was excellently incorporated in the systematics provided by the created unified picture for hadron spectra. Such state really exists, and it lives just on the second storey in the Kaluza-Klein tower of KK excitations for the $\rho J/\psi$-system; see Table 1. As is seen from Table 1, there is a wonderful agreement of experimentally measured mass with theoretically calculated one.

In this note we present the build of the Kaluza-Klein tower of KK excitations for the $\omega J/\psi$-system. In according to the general physical law we built the Kaluza-Klein tower of KK-excitations for the $\omega J/\psi$ system by the formula

$$M_n^{\omega J/\psi} = \sqrt{m_\omega^2 + \frac{n^2}{R^2}} + \sqrt{m_{J/\psi}^2 + \frac{n^2}{R^2}}, \quad (n = 1, 2, 3, ...), \tag{1}$$

where R is the same fundamental scale established before; see [7] and references therein for the details, and $m_\omega = 782.57$ MeV, $m_{J/\psi} = 3096.87$ MeV have been taken from PDG. The such built Kaluza-Klein tower is shown in Table 2. As seen in Table 2, the Belle measured state just lives in 7th storey within this Kaluza-Klein tower.

Our conservative estimate for the widths of KK excitations looks like

$$\Gamma_n \sim \frac{\alpha}{2} \cdot \frac{n}{R} \sim 0.4 \cdot n \, \mathrm{MeV}, \tag{2}$$

where n is the number of KK excitation, and $\alpha \sim 0.02$, $R^{-1} = 41.48\,\mathrm{MeV}$ are known from our previous studies [7]. This gives $\Gamma_2(X(3782) \to \rho J/\psi) \sim 0.8$ MeV and $\Gamma_7(X(3945) \to \omega J/\psi) \sim 2.8$ MeV. The Belle measured width $\Gamma_{exp}(X(3945) \to \omega J/\psi) \sim 100$ MeV is too broad and cannot simply be explained. In general, the broad peaks in the hadron spectra are interpreted as envelope of the narrow peaks predicted in our approach, or some additional model-dependent assumptions are needed. As it follows from Table 2, we predict the narrow states $M_6^{\omega J/\psi}(3928)$ and $M_8^{\omega J/\psi}(3965)$ which are near the observed state $M_7^{\omega J/\psi}(3945)$. However, the experimentally used 40 MeV-wide bins of $M(\omega J/\psi)$ cannot obviously resolve these predicted narrow states. This only means that a further, much more careful experimental studies with a higher statistics and better mass resolution are very desired.

In summary, newly performed experimental studies by the Belle Collaboration are excellently incorporated in the unified picture for hadron spectra developed early. We would like to emphasize once again that the main advantage of our approach to hadron spectroscopy is that all calculated numbers for the masses of hadron states do not depend on a special dynamical model but follow from fundamental hypothesis on existence of the extra dimensions with a compact internal extra space. Our analysis shows that the measured values for the masses of the BELLE states exactly coincide with the calculated masses of the states living in the corresponding KK towers. We expect that new experiments with better statistics and higher mass resolution will appear in the near future to extend our knowledge and to enrich our understanding the true nature and the properties of the newly discovered states.

References

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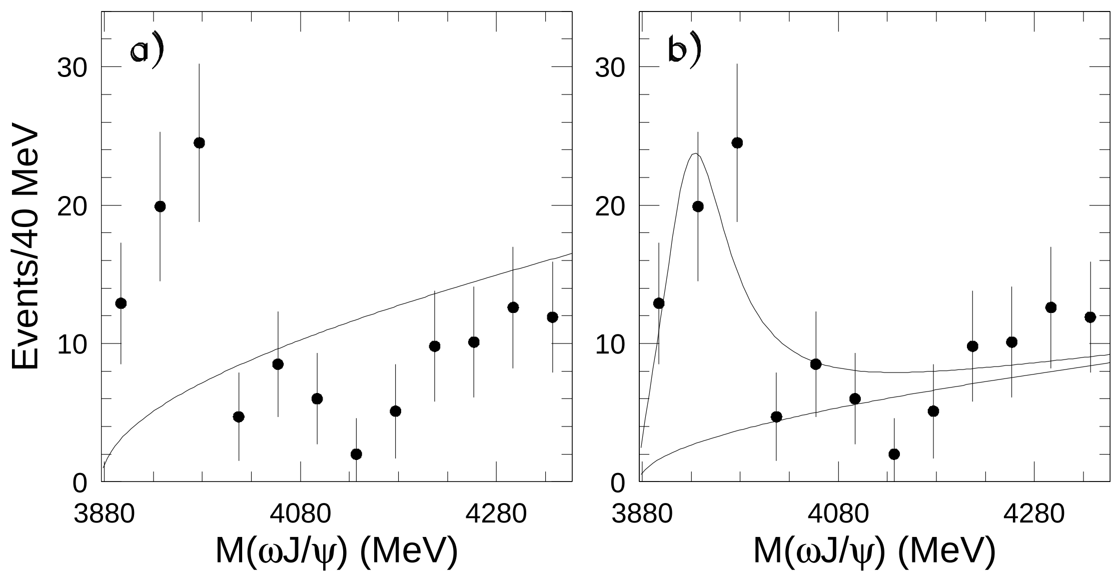

Figure 1: The $\omega J/\psi$ invariant mass in $B \to K\omega J/\psi$ decay presented in Ref. [1]. The curve in **(a)** indicates the result of a fit that includes only a phase-space-like threshold function. The curve in **(b)** shows the result of a fit that includes an S-wave Breit-Wigner resonance term. The details for the fits shown see in original paper [1].

Table 1. Kaluza-Klein tower of KK excitations for $\rho J/\psi$ system and $D_{sJ}(3872)$-meson.[2]

n	$M_n^{\rho J/\psi}$ MeV	$M_{exp}^{\rho J/\psi}$ MeV
1	3867.57	
2	3871.74	3871.8±0.7±0.4
3	3878.67	
4	3888.30	
5	3900.58	
6	3915.41	
7	3932.73	
8	3952.42	
9	3974.39	
10	3998.54	
11	4024.75	
12	4052.92	
13	4082.95	
14	4114.74	
15	4148.19	
16	4183.22	
17	4219.74	
18	4257.68	
19	4296.95	
20	4337.48	
21	4379.23	
22	4422.11	
23	4466.09	
24	4511.11	
25	4557.11	
26	4604.07	
27	4651.93	
28	4700.65	
29	4750.21	
30	4800.57	

[2]The Table extracted from Ref. [7]. The recent value for the Belle measurements of the X(3872) mass is 3872.0±0.6(stat)±0.5(syst) MeV.

Table 2. Kaluza-Klein tower of KK excitations for $\omega J/\psi$ system.

n	$M_n^{\omega J/\psi}$ MeV	$M_{exp}^{\omega J/\psi}$ MeV
1	3880.82	
2	3884.94	
3	3891.77	
4	3901.28	
5	3913.40	
6	3928.05	
7	3945.16	3945 ± 10
8	3964.62	
9	3986.35	
10	4010.24	
11	4036.18	
12	4064.09	
13	4093.84	
14	4125.36	
15	4158.54	
16	4193.31	
17	4229.56	
18	4267.24	
19	4306.26	
20	4346.55	
21	4388.05	
22	4430.71	
23	4474.46	
24	4519.26	
25	4565.06	
26	4611.82	
27	4659.48	
28	4708.02	
29	4757.41	
30	4807.60	